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EXTENDED ARRAY EVALUATION PROGRAM

Quarterly Report No. 3

1 October 1971 to 31 December 1971

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TEXAS INSTRUMENTS INCORPORATED
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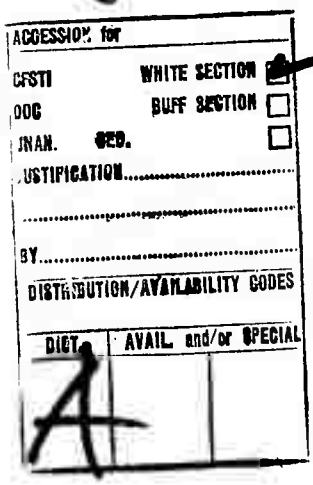

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13. ABSTRACT

This third quarterly report summarizes progress under the Extended Evaluation of ALPA, NORSAR, and LPE programs, Contract F33657-71-C-0843. Work to date in the following areas is summarized:

- ALPA evaluation,
- NORSAR long period evaluation
- NORSAR short period evaluation,
- LPE evaluation
- Network analysis,
- Adaptive processing
- High-resolution frequency-wavenumber analysis

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SECTION I
INTRODUCTION AND SUMMARY

This third quarterly report summarizes progress made during the past quarter, 1 October 1971 to 31 December 1971, on the Extended Evaluation of ALPA, NORSAR and LPE Data program being conducted by Texas Instruments Incorporated at the Seismic Array Analysis Center in Alexandria, Virginia. The program consists of the following seven tasks:

- Continued evaluation of the Alaskan Long Period Array (ALPA)
- Evaluation of the long period Norwegian Seismic Array (NORSAR)
- Evaluation of the short period Norwegian Seismic Array
- Evaluation of the stations of the Long Period Experiment (LPE) network
- Investigation of network processing and analysis techniques
- Adaptive processing studies
- Investigation of high-resolution frequency-wave number spectral estimation techniques

The software required to perform the evaluation was developed under a previous contract (Contract F33657-69-C-1063). During the past quarter no modifications were made to existing software, with the exception of one program (NSPRM) of the NORSAR Short Period Package. Because certain options in this program (notably, the calculation of short period discriminants section) have not yet been tested, submission of updated documentation will be deferred until the fourth quarter.

ALPA evaluation continued during the third quarter. About 70 additional events were processed, including many for which the full 19-element array was operational. Processing was directed towards obtaining an estimate of the ALPA surface wave detection threshold for full-array operation.

During the third quarter 36 additional NORSAR long period events and some additional noise samples were processed. Eighteen large signal-to-noise ratio events have been obtained; these are being used to study signal characteristics, signal degradation due to beamforming, and as master events for matched filtering. Initial array processing results indicate that multichannel filtering is not significantly better than beamforming in the .02 to .06 Hz band, and that signal degradation is typically 2 dB; these results are similar to those obtained for ALPA. Matched filtering improvements are excellent (more than 6 dB) for the Turkey and Kurile regions, but tend to be low for the Sinkiang area.

An additional 35 NORSAR short period events (and 30 associated noise samples) were processed during the third quarter. These data generally confirmed earlier results reported in Quarterly Report No. 2 (Texas Instruments, 1971). Noise levels are very stable across the array, but lower summertime levels are suggested. Time delay anomalies must be included for proper array beamforming, and appear to be stable for a given region. Diversity-stack beamforming usually does not increase the signal-to-noise ratio (relative to equally-weighted beamforming), except for a few events where 2 to 3 dB was obtained. The NORSAR short period detection threshold for Sino-Soviet events appears to be below $m_b = 4.3$, but insufficient data have been processed as yet to make a more definitive statement.

LPE processing continued during the third quarter. Some digital data have been received from seven stations; Australia, Thailand, Alaska, Spain, Israel, Norway and Ogdensburg. However, digital data recordings are quite scattered and we have only a few events which were recorded at more than two stations. About 200 signals were processed and analyzed during the third quarter. The analysis was directed toward analyzing the ambient noise at each station and obtaining a preliminary estimate of the surface wave detection

capability at Thailand, Alaska, Spain and Israel. In addition, earthquake signal amplitudes at 40 and 20 seconds were compared and indicated that 20-second amplitudes were larger typically by a factor of two.

Work was begun on the Network Evaluation Task during the third quarter. Planning of the studies to be performed under this task has begun and will be completed during the fourth quarter, when the analysis concepts also will be checked out on a limited data base.

A special report covering the theoretical investigations of the adaptive processing task was prepared during the third quarter and will be submitted for approval in the near future. Work concerning practical operation of the on-line adaptive processing for ALPA data will be completed during the fourth quarter.

A special report covering the theoretical aspects of the high resolution wavenumber spectral estimation task was prepared during the third quarter and will be submitted shortly. This report included discussion of the stability of various estimates and a comparison of the conventional, maximum-likelihood, maximum entropy and eigenspectra techniques. Application of these techniques to real data will be undertaken during the fourth quarter.

SECTION II

ALPA EVALUATION

1. Current Status

During the past quarter approximately 70 events recorded at ALPA have been processed. Some of these events occured in the months of July, August, and September when the full 19-element array was operational. Included in this latter category was a swarm of 37 Sakhalin Island events which occurred on September 6, 7, and 8.

Routine noise analysis has been performed on a suite of 18 ALPA one-hour noise samples recorded at approximately ten-day intervals over the period day 121 to day 312 of 1971. Comparison of these data with noise recorded at NORSAR indicates that the noise levels at the two arrays are comparable except on occasional days when anomalously high levels are observed at ALPA. Examination of the ALPA noise levels on a site-by-site basis shows that the seven-element hexagonal subarray located in the northeast quadrant of the full array is consistently as quiet or quieter than the remaining sites of the array.

Previous estimates of the ALPA surface-wave detectability have been obtained with data from the nine-element array which was operational during 1970. The number of events which have been processed to date with the full array does not permit meaningful estimation of the full array detectability. An initial estimate of the gains to be expected with the full array has been obtained by processing a suite of 15 noise samples recorded over the period day 231 to day 337 of 1971. Diversity stack beamsteers were formed for each noise sample using surface wave velocities and a 340^{o} source direction. Two beams were formed in each case, one with all available sites of the array, and the other with all available sites of the nine-element subarray which was operational

in 1970. The output noise levels of these beams indicate that the detection threshold with the full array should be about 0.1 M_s units lower than with the nine-element array.

2. Future Plans

Routine processing of events will continue. With the full array now available, particular emphasis will be placed on the critical magnitude range, m_b = 3.5 to 5.0. This will permit estimation of the full array detection threshold. Analysis of selected noise samples at approximately ten-day intervals will continue.

SECTION III

NORSAR LONG PERIOD EVALUATION

1. Current Status

During the past quarter 36 events from the Sino-Soviet bloc were edited. These events had a magnitude (m_b) range of from 4.1 to 5.6. The total number of events edited through the third quarter is 75. Approximately nine additional noise samples have been obtained at ten day intervals for a total of 23 samples spanning the period from day 121 to day 341.

The suite of large signals for signal analysis now contains 18 events. Although no system response calibrations are available, the data appear to be well equalized and surface wave magnitudes computed at each site for these events show a variation of less than 0.1 magnitude units. Signal similarities measured on ten events indicate characteristic difference in similarities between sites in-line along the propagation path and sites in-line perpendicular to the path with the former having much larger similarities. This is true over a wide range of azimuths although it is stronger for some directions than others. Initial testing of a simple model indicates that these effects may be due to multi-path interference. Further investigation into this effect is under way.

Power density spectra and wavenumber spectra have been measured for all noise samples obtained. Measurements of the RMS noise output in the 20-40 second band of a beam steered to different directions continue to show that the noise is generally strongest between 0^o to 100^o as previously reported. Noise levels also appear to be increasing toward the end of the year with the onset of winter.

Array processing continued with analysis of the relative performance of multichannel filters (MCF's) and beamsteering. Array gain loss from

beamsteering measured with large signal-to-noise ratio events generally varies between 0.5 to 2.5 dB which is not significantly different from ALPA. Eight samples have been used to design MCF's for comparison to beamsteering. Only two of these samples were sufficiently long to allow MCF's of some reliability to be computed. Within the design gate MCF performance was only 1 to 2 dB better than beamsteering for off-design noise, the MCF performance (noise rejection) was essentially equivalent to beamsteering performance. It does not appear that routine design and application of multichannel filters at NORSAR will be of practical use.

Matched filtering using chirp and master waveform filters have been completed on approximately 25 events. Three passbands are being evaluated: 0.020-.059 Hz, 0.025-.055 Hz, and 0.025-.051 Hz. Regions which have been studied primarily are Turkey, the Kuriles and the Sinkiang region. Master waveforms have been obtained for these regions. Generally large improvements (6 to 10 dB) have been obtained for the Turkey and Kurile regions. Results from the Sinkiang region are generally poor with both types of matched filters. The signal duration is much shorter then expected with possibly strong interference. It also appears that the arriving energy is from both sides of the minimum point on the group velocity curve. This would preclude useful gains using simple chirp filters. Particular attention to the central Asian region is planned with the aim of understanding the peculiar waveforms and obtaining better master events.

2. Future Plans

Future plans are to obtain an ensemble of small magnitude events (m_b between 3.5 and 4.3) to get a preliminary measure of the NORSAR detection capability. Detection thresholds will also be computed using the equivalent M_s of the noise samples. MCF's will be designed for one or two noise samples

using only the A and B ring to further compare the MCF and beamsteer noise rejection.

Matched filtering will be applied to more events from the Central Asian region. Several events from near Semipalatinsk have been edited and will be processed as soon as that area becomes better understood. In addition, several events from the regions near the Caspian Sea and eastern Siberia will be examined.

SECTION IV

NORSAR SHORT PERIOD EVALUATION

1. Current Status

During the third quarter of this contract, approximately 35 signals and 30 noise samples were processed, using data recorded from the full 132-sensor array. Most of the data was from the period 1 March 1971 to 1 June 1971.

Standard noise analysis revealed that noise levels from sensor to sensor varied little within any particular sample. From sample to sample, noise spectral shape varied little. Broadband noise levels, however, tended to drop for data later during the year, (around June), suggesting a seasonal variation in NORSAR short period noise levels.

Signals continued to show significant amplitude variations between subarrays and moderate deviations from the intersubarray delays expected from plane-wave propagation. Delay anomalies were mapped as a function of event location for each subarray. Consistent anomalies were obtained for suites of events from the Kurile Islands and Central Asia respectively.

For each event, signal-to-noise ratios were calculated for a reference subarray, for the plane-wave array beam, for the adjusted-delay array beam, and for the diversity-stack array beam. Plane-wave beam signal-to-noise ratios normally exceeded those of the reference subarray by 0 to 6 dB, although in some cases they were as much as 6 dB lower. Improvements of the adjusted-delay beam relative to the plane-wave beam was generally in the range 3 to 6 dB, while that of the diversity-stack beam relative to the adjusted-delay beam was 1/2 to 1 dB, with a few signals showing 2 to 2 1/2 dB improvement.

All events of magnitude 4.3 or higher were detected, but no conclusive detection was possible on the one processed event of magnitude 3.8. No signals between magnitude 3.8 and 4.3 have been processed to date.

2. Future Plans

Routine processing of events will continue. An effort to obtain events between magnitude 3.8 and 4.5 and noise samples spread over the entire year will be made. This will provide data needed to obtain a preliminary estimate of the array detection threshold and to observe the fluctuations of broadband noise level as a function of the time of year.

SECTION V

LPE EVALUATION

1. Current Status

During the past quarter routine event processing has continued for six LPE stations: Thailand, Alaska, Spain, Israel, Norway and Ogdensburg. Routine processing has included investigation of station noise levels by analysis of noise power density spectra and computation of 20-40 second RMS levels. The routine analysis also has included a study of signal detection capability and calculations for $M_S : m_b$ discrimination analysis. The number of signals analyzed for each station is shown in Table 1. Note that the lack of Norway calibration data has restricted our analysis because no calculation of signal M_S values, RMS noise levels, and absolute noise power density spectra can be made. No data for the Australian station was processed due to tape format problems.

TABLE I

SIGNALS ANALYZED DURING THE THIRD QUARTER AT LPE STATIONS

Station	Number of Signals Analyzed
Australia	–
Thailand	26
Alaska	52
Spain	31
Israel	25
Norway	13
Ogdensburg	51

Preliminary results for Thailand, Alaska, Spain and Israel have been obtained for:

- noise spectral shape
- RMS noise levels
- surface wave detection capability
- behavior of M_S:m_b

These will be reported in detail in upcoming reports. In addition a study of earthquake signal amplitudes at 20 and 40 seconds has been made which shows that 20-second amplitudes are larger than those at forty seconds typically by a factor of two.

2. Future Plans

During the coming quarter we intend to process as many signals as possible at each station and to continue analysis of the station noise fields on a routine basis. In addition, 16-mm films of all library tape data and all events will be made, after final approval of the film format has been given by VSC.

SECTION VI

NETWORK EVALUATION

1. Current Status

The network evaluation task has been severely hampered by the lack of multi-station data. In the last quarter a limited amount of data have become available and detection of network evaluation procedures has begun.

Individual site seismic noise characteristics are being examined under the LPE task with the intent of establishing mean RMS levels and variability as a function of frequency and time. The eventual use of these data is to provide a basis for estimating the influence of noise measured in RMS terms upon signal detectability. Once individual station capabilities are known, the detection capabilities and probability of detection by the network of stations will be investigated using available network capability software.

To date, several hundred noise spectra in the time immediately preceding signal onsets have been obtained from the operational sites. These will be compiled and statistical characteristics of means and variability determined. The results will not include any estimate of noise characteristics related to seasonal effects because of the limited operational periods of some sites. System calibrations are also in doubt during some time periods, so only relative signal and noise conditions are available for part of the data. Noise characteristics will be compared among stations in order to determine the relative stabilities, levels, and frequency contents.

2. Future Plans

During the fourth quarter a detailed plan covering all aspects of network evaluation, including:

- detection capability
- network level processing
- interferring event studies
- radiation pattern studies

will be formulated and tested on a limited sample of data.

SECTION VII

ADAPTIVE PROCESSING

1. Current Status

A significant problem in the use of adaptive filters stems from the fact that the stability of the algorithm is related to the value of eigenvalues corresponding to the principle components of the noise matrix. The rate of adaptation is limited by the larger eigenvalues, and as a result the algorithm is not effective against weak noise components. The convergence rate on weak noise components can be increased by resorting to a multiloop algorithm.

A comparison of single loop with two loop processing has been made. The study was done with synthetic data designed to simulate a typical multi-source noise environment. Results showed that some additional improvement in rejection of the weaker noise components could be obtained with the multiloop method but that the decrease in total RMS noise was quite small. An approval copy of the resulting special report will be submitted in the near future.

2. Future Plans

During the fourth quarter efforts will be concentrated on running the adaptive processor at SAAC on ALPA data in order to obtain additional experience with on-line adaptive processing methods.

SECTION VIII

HIGH-RESOLUTION FREQUENCY-WAVENUMBER SPECTRAL ANALYSIS

1. Current Status

A comparison has been made regarding the effectiveness of various techniques available for frequency-wavenumber spectral analysis. These include conventional beamsteer, maximum likelihood, maximum entropy, and principle components or eigenspectral analysis. The comparison was made both on synthetic noise data and on a sample of seismic noise recorded at TFO. Results indicated that the eigenspectra technique had the best capability for recovering weak components in the noise field.

2. Future Plans

During the fourth quarter effort will be concentrated on comparing several techniques on actual seismic noise data.

SECTION IX

REFERENCES

1. Texas Instruments Incorporated, 1971: Extended Array Evaluation Program, Quarterly Report No. 2, Contract F33657-71-C-0843, January.